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Soil carbon sequestration potential as affected by soil physical and climatic factors under different land uses in a semiarid region

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ABSTRACT

Carbon (C) sequestration in soil is recognized as a possible solution for climate change mitigation. Different land uses may alter carbon sequestration in soil. In the semiarid regions of central Iran, during the last decades, land use changes from native cover to farmlands have altered the C sink role of soil to a source of CO_2 emission to the atmosphere. This study was conducted to evaluate and compare changes and the potential of soil organic carbon (SOC) sequestration from 1988 to 2014, under different land uses, in western central Iran (Lordegan). The land uses included pasture, forest, rain-fed, and irrigated farmlands. Soil (450 samples) from 50 points across the study basin (390 km^2) was collected in three depth increments (0–5, 5–15 and 15–30 cm) during three sampling times (June and November 2014, and June 2015). Mean SOC concentrations in the pasture, forest, rain-fed and irrigated farmlands were 10.3, 20.2, 9.2 and 10.1 g kg^{-1}, respectively. The SOC concentration in the forest soil was significantly greater than the other land uses, and any reduction in forestland area would lead to the SOC stock decline. About 1390 Gg organic carbon was found to be stored in the top 0–30 cm depth of the study area. Comparing land use maps between 1988 and 2014 indicated an alteration in the relative contribution of each land use across the study area leading to SOC stock reduction by 100 Gg carbon during this period. The results showed that all studied soils comprised non-complexed clay, suggesting a considerable potential capacity for sequestering carbon. The results also indicated that the SOC controlling factors varied considerably among different land uses and soil depths. Mean weight diameter of aggregates (MWD), bulk density, clay and sand content, and altitude were identified as the important controlling variables by the stepwise multiple linear regression analysis.

1. Introduction

A growing concern over the increasing atmospheric greenhouse gases concentration and global warming has been reported in the recent decades (IPCC Climate Change, 2013). Climate change has become a crucial challenge for all nations, resulting in severe effects on the environmental components, such as temperature rise, these, in turn, have led to ecosystem degradation (Ko et al., 2017; Shen and Lukes, 2015).

Carbon sequestration in soil is a possible solution to mitigate climate change via converting atmospheric CO_2 into stable soil organic carbon; thus, it has the additional benefit of improving soil quality (Minasny et al., 2017). Soils are the main carbon sink/source and an important component of the global C cycle (Faggian et al., 2012), containing about 1206 Pg organic carbon (OC) in the upper 1 m depth (Hiederer and Köchy, 2011) which is significantly greater than the atmospheric carbon stock (800 Pg) (Zdruli et al., 2017). Therefore, a small increase in the soil carbon stocks plays an important role in reducing greenhouse gases of the atmosphere. According to this idea, the '4 per mille Soils for Food Security and Climate' was launched at the COP21 conference in Paris in December 2015. This program aims to compensate the global emissions of greenhouse gases through increasing soil organic carbon by 0.4% per year (Minasny et al., 2017).

The amount of OC in soil at any given time depends on the long-term balance between the carbon inputs and the losses rate. These rates are controlled by factors including soil attributes (e.g., soil lithology and texture), climatic variables (e.g., mean annual temperature and precipitation), biotic characteristics (e.g., microbial population and biomass production), and anthropogenic factors (such as land use and management) (Albaladejo et al., 2013; Zdruli et al., 2017). These factors affect SOC stock through influencing the SOC decomposition rate,

Abbreviations: SOC, soil organic carbon; SOCC, soil organic carbon concentration (g kg^{-1}); SOCD, soil organic carbon density (Mg ha^{-1}); SOCS, soil organic carbon stock (Mg); CC, complexed clay; NCC, non-complexed clay; COC, complexed organic carbon; NCOC, non-complexed organic carbon

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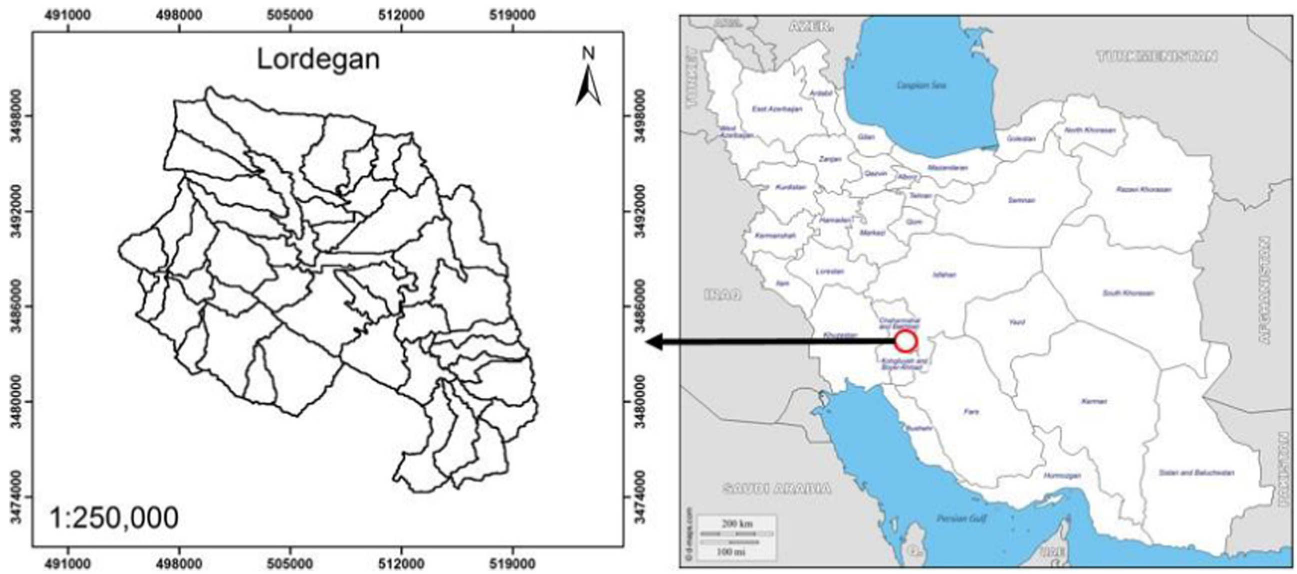

Fig. 1. Location of the study area (Lordegan, left) within the Iran's map.

SOC absorption, and stabilization, altering moisture regime and the vertical redistribution of SOC in the soil profile (Akpa et al., 2016; Dorji et al., 2014; Six et al., 2002b).

Some adverse consequences of negative carbon budget include soil biodiversity reduction, aggregate disruption, soil structure degradation, exacerbation of erosion hazards, green water supply reduction, increased drought risk, elemental cycling disruption, and soil fertility reduction (Zdruli et al., 2017). Positive carbon budget could be achieved through the restoration of low-biomass land use to their pristine ecosystems, or well-managed land uses (Akpa et al., 2016; Albaladejo et al., 2013; Fang et al., 2012; Poeplau and Don, 2013).

The organic carbon that is attached to soil clay becomes more stable, and the maximum amount of complexed or stable organic carbon can be calculated as C_{MAX} = clay / *n*, which is called "capacity factor" (Carter et al., 2003; Hassink, 1997). Therefore, the extra amount of the stable SOC that is stored in the soil can be computed by subtracting the capacity factor (the maximum possible amount) and the actual amount of the complexed organic carbon (COC). Dexter et al. (2008) proposed a simple algorithm to divide SOC into complexed and non-complexed organic carbon. The method could be used to estimate the maximum amount of complexed or stable organic carbon in carbon sequestration context.

Land use change affects SOC (Poeplau and Don, 2013) via the conversion of the natural land cover to agricultural ecosystems (Post and Kwon, 2000; Wilson et al., 2008). Generally, shifting from forests or virgin lands to cultivation leads to a reduction in SOC stocks by an average of almost 20–50% (Gregorich et al., 2005; Guo and Gifford, 2002). Forest soils with great amounts of organic matter represent a potential sink for sequestering atmospheric CO_2; thus they can be a source of greenhouse gases emission as a result of mismanagement and decomposition of the soil organic carbon (Lal, 2009; Zimmermann et al., 2007). The contribution of land use changes to CO_2 emission reaches 20% of atmospheric CO_2 due to the loss of SOM and biomass (Zdruli et al., 2017).

The agricultural sector has a considerable contribution to CO_2 emission through tillage, irrigation, cropping systems, fertilization and other operations which intensify global warming. Thus, there is a demand for SOC stocks spatial patterns information about agricultural activities and land use changes (Akpa et al., 2016; Lal, 2005).

Zagros forests are the vastest tree land (an area of about 5 million ha) in the semiarid region of central and western Iran. Although the contribution of these forestlands in wood industry is negligible, they play an important role in soil and water conservation and environmental functions in the region. A considerable part of these forests has been changed to farmlands in the last 40 years. The intensive deforestation and over grazing have declined soil quality and changed carbon balance between soil, biosphere, and atmosphere in the region (Mojiri et al., 2012).

In spite of many studies conducted on SOC stocks, there is a need to quantify the relationship between the SOC content and important influential factors (Lal, 2004). Establishing carbon stock inventories is required to determine a baseline and to estimate carbon stock changes (Leifeld et al., 2005). Lack of SOC distribution data, especially in the semiarid regions, is a main gap in the soil science (Hoffmann et al., 2012), thus leading to inappropriate management practices.

Therefore, the aims of this study were (1) evaluating the temporal changes of SOC, (2) determining soil carbon sequestration potential, and (3) outlining the main factors controlling variation in carbon sequestration under various land use types in Lordegan semiarid region (the central and western part of Iran). We hypothesized that the land use type could exert a significant influence on the SOC stock variation in this region.

2. Materials and methods

2.1. Study area

The study location was Lordegan (central, Iran), with the area of 390 km^2, between 31°23′ and 31°38′ N, 50°56′ and 51°13′ E (Fig. 1), with an altitude ranging between 1764 and 2856 m above the sea level. Soil texture in the region, which ranged from clay loam to silty clay loam, was developed on a calcareous parent material. The average yearly temperature and precipitation are 14.9 °C and 650 mm, respectively. The rainy season extended from October to May, with a maximum during November and February (Fig. 2). The land use distribution in the study area included forest (5%), pasture (47%), and the rest was used for irrigated and rain-fed farming.

The initial natural land cover used to be oak forests (*Quercus brantii* Lindl) which has been deforested continuously by the time. The deforested area was converted to agricultural lands with conventional tillage (both irrigated and rain-fed farming according to water availability). Wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.) were found to be the dominant crops in the agricultural lands (Nourbakhsh, 2007).

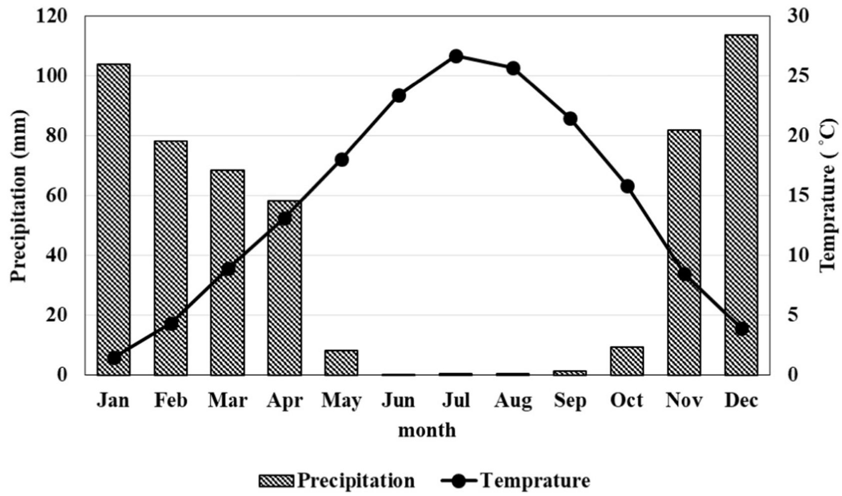

Fig. 2. Average monthly precipitation and air temperature in the study area.

2.2. Soil sampling and data collection

The study area was delineated into several subunits using the SWAT model (Winchell et al., 2013). The division was done according to the dominant land use, soil types, and topography. In this manner, the area was divided into 50 uniform subunits for soil sampling. The 50 sampling points consisted of 12, 9, 12 and 17 points for pasture, forest, rainfed and irrigated farmlands, respectively. Soil samples were collected three times in June and November 2014, and in June 2015. Soil samples were taken within each subunit at three depth increments (0–5, 5–15 and 15–30 cm), resulting in 450 samples (50 points × 3 depths × 3 times). Each sample was a mixture of 4 sub-samples (at each layer) collected from an area of about 900 m^2 (30 m × 30 m) plot in a representative part of the subunit with a uniform soil and land use. During the first sampling program, the sampling points were flagged and the second and third sampling programs were followed according to the predetermined points. Undisturbed soil core samples were also taken in each layer of the sampling points using a stainless steel ring (volume: 100 cm^3) for measuring the soil bulk density (Arshad et al., 1996).

The SOC concentration was measured according to the wet dichromate oxidation procedure (Nelson and Sommers, 1982). The hydrometer method outlined by (Gee and Bauder, 1986) was employed to determine the particle size distribution and soil texture. Aggregate mean weight diameter (MWD) was determined using the wet sieving method according to Cambardella and Elliott (1993).

The meteorological data (average monthly mean temperature and precipitation) were obtained from Iran Meteorological Organization. To get the temperature and precipitation data for each sampling point, the IDW interpolation method was conducted in Arc GIS 10.1. The land use maps were obtained from Iran Ministry of Agriculture (Yekom Consulting Engineering Co, 1988).

2.3. Data processing and statistical methods

To avoid soil organic carbon stock overestimation, soil bulk density was corrected according to Poeplau et al. (2017), and SOC density (SOCD, Mg ha^{-1}) was calculated using Eqs. (1) and (2):

$$FSS_i = \frac{Mass_{fine\ soil}}{Volume_{sample}} \times H, \tag{1}$$

$$SOCD_i = SOCC_{fine\ soil} \times FSS_i \tag{2}$$

where FSS_i (Mg ha^{-1}) is the fine soil stock in the layer i, H (cm) is the thickness of the layer i, and $SOCC_{fine\ soil}$ (%) is the organic carbon concentration of the fine soil in the layer i. To obtain SOC density for the 0–30 cm depth, a weighted mean of SOC density was calculated according to the depth of the sampling layers.

The soil organic carbon stock or storage is the actual amount of SOC in a given soil depth and given area. It is calculated according to Eq. (3):

$$SOCS = SOCD \times A \tag{3}$$

where SOCS is the soil organic carbon stock (Mg C), SOCD is the soil organic carbon density (Mg C ha^{-1}), and A is the area (ha) (Wu et al., 2003).

The potential carbon sequestration indicates the amount of carbon which could be sequestered if any land use type is converted back to the pristine land cover. This could be obtained from the difference of the mean SOC density of a given land use and the respective origin land use (Eq. (4)):

$$C_{seq} = \sum_{j=1}^{m} SO\bar{C}D_{nj} - SO\bar{C}D_{uj} \tag{4}$$

where C_{seq} (Mg C ha^{-1}) is the potential carbon sequestration, $SO\bar{C}D_{nj}$ (Mg C ha^{-1}) is the mean SOC density for origin or native land cover, $SO\bar{C}D_{uj}$ (Mg C ha^{-1}) is the mean SOC density for any other land use within the same study region, and m is the number of land uses (Akpa et al., 2016). The native land use type in our study of area was forest.

In order to calculate complexed and non-complexed organic carbon and clay, the carbon saturation concept proposed by Dexter et al. (2008) was used (Eqs. (5)–(8)). Then, the additional amount of complexed organic carbon which could be stored in the soil was estimated using Eq. (9):

$$CC = (nOC) \text{ if } (nOC<clay), \text{ else } CC = clay \tag{5}$$

$$NCC = (clay-CC) \text{ if } (clay-CC) > 0, \text{ else } NCC = 0 \tag{6}$$

$$COC = OC \text{ if } OC < (clay/n), \text{ else } COC = (clay/n) \tag{7}$$

$$NCOC = OC - COC \text{ if } (OC - COC) > 0, \text{ else } NCOC = 0 \tag{8}$$

$$PAOC = (C_{MAX} - COC) \text{ if } (C_{MAX} - COC)^{>}0, \text{ else } PAOC = 0 \tag{9}$$

where CC and NCC are complexed and non-complexed clays (g kg^{-1}), COC and NCOC are complexed and non-complexed organic carbons (g kg^{-1}), respectively, and n is the ratio of clay to organic carbon (OC), where clay is assumed to be saturated with OC, which is considered equal to 10 according to Dexter et al. (2008). Therefore, saturation line was defined by COC = Clay / n (i.e., n = 10). PAOC (g kg^{-1}) is potential additional complexed organic carbon which indicates the potential capacity for sequestering carbon, and C_{MAX} (g kg^{-1}) is the maximum possible amount of complexed organic carbon according to clay / n (n = 10) (Dexter et al., 2008).

The SOC concentration (g kg^{-1}) data within the four land uses, and three depths were separately subjected to the analysis of variance. One-way ANOVA was used for the statistical analysis of data instead of two-way ANOVA. Because the depth increments were not equal (i.e., 0–5, 5–15 and 15–30 cm) and weighted mean was used to determine the SOC in the 0–30 cm layer. Whereas in the two-way ANOVA, all data are being equally used together in the calculations. Moreover, our purpose was to compare the SOC value in each land use and soil depth with its own previous situation which was easily achievable through the one-way ANOVA. Means' comparison was done using Duncan's multiple range test in each section ($P < 0.05$). To investigate the trend of carbon sequestration in soil, the same analysis was done for the SOC density (Mg ha^{-1}) data in the three sampling times. A Spearman test was used to establish the correlation between SOC concentration and the soil attributes including soil bulk density, clay, silt, sand, and aggregate mean weight diameter (MWD), and environmental variables such as precipitation, air temperature, altitude and land slope in each land use and depth. The stepwise multiple linear regression analysis was also conducted to identify which soil attributes or environmental variables best predicted the soil SOC concentration. The analysis was done for three soil depths, and four land uses separately. Before doing the regression analysis, the data was checked for multicollinearity using variance inflation factor (VIF) tool. Multicollinearity occurs when the predictors (i.e., independent variables) are strongly correlated together, and it can adversely affect the regression results. By relying on the VIF values, the annual precipitation was omitted. All statistical analyses were performed using SPSS 20.0 (SPSS, 2011).

3. Results

3.1. Land use types and the SOC concentration

The SOC concentration in the forest soil was significantly higher than that in the other land uses (Table 1). In the topsoil, the lowest SOC concentration was obtained in the soils under rain-fed farming. No significant differences were observed between the pasture, rain-fed and irrigated farming regarding SOC concentration; in these three land uses, it was, on average, 50% less than that of the forest soil. The SOC concentration coefficient of variance (CV) ranged from 19% to 42% (Table 1).

In general, the trend of SOC concentration was decreasing with depth (Table 1). For all land uses except rain-fed farming, a significant reduction in SOC concentration was observed from the 0–5 cm layer to the 5–15 cm one. The change in subsurface layers (between 5–15 and 15–30 cm) was not statistically significant.

3.2. Temporal changes of SOC density

The results showed that there were no significant temporal changes in the SOC density. However, different trends were observed for various land uses regarding SOC density (Fig. 3).

In the pasture soil, there was a decreasing trend in SOC density, but in the forest, rain-fed and irrigated farmlands, slight fluctuations were observed, and the SOC density changes were insignificant. The temporal changes of SOC density in each layer of a given land use were similar to the observed pattern for the related averaged one in that land use. When the SOC density was calculated per cm of depth, it was decreased with depth in all land uses, except rain-fed farming which was approximately constant across soil layers.

Table 1
Mean and coefficient of variation (CV) of the soil organic carbon concentration (SOCC) (g kg^{-1}) according to land use types at different depths.

Land use	0–5 cm		5–15 cm		15–30 cm	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
Pasture	12.77^{a}	29	10.68^{a}	29	9.21^{a}	24
Forest	28.16^{b}	42	20.69^{b}	27	17.3^{b}	29
Rain-fed farm	9.36^{a}	26	9.21^{a}	19	9.17^{a}	28
Irrigated farm	13.15^{a}	39	9.57^{a}	28	9.51^{a}	38

Different letters mean significant differences in each depth between land uses at $P < 0.05$, according to Duncan's test.

3.3. Distribution of total organic carbon storage across the study area

Since forest soils contained the greatest SOC concentration in all the depths, the calculated SOC density in this land use was bigger than that of others as well (mean forest SOC density: 24.88 Mg ha^{-1}) (Table 2).

By using Eq. (3), the organic carbon stored in 0–30 cm depth was calculated to be 1389.6 Gg. The irrigated farmlands (16,000 ha) contained 43% of the total SOC density, which was followed by pasture (18,320 ha), forest (2024 ha), and rain-fed farming (2116 ha) with 42%, 10%, and 5%, respectively. About 88% of the land coverage were pastures and irrigated farm lands (Table 2). Thus, unlike their low SOC density, compared to the forest soils, pastures and irrigated farm lands had considerable SOC storage in the area.

Due to the lack of reliable data on the history of SOC variations in the region and insignificant changes of SOC density during our study time, it was assumed that the SOC density was constant in each land use type over the time. Therefore, to evaluate the changes of the SOC stock during a long period of time, it was calculated for 1988 using the current SOC density data and an old land use map generated in 1988.

The results showed the relative contribution of each land use was changed during the time and these changes led to different amounts of SOC stock in the soil. While the area of pasture and forest was reduced by 17% and 64%, the areas covered by irrigated and rain-fed farmlands were increased by 1.6 and 2.5 times, respectively, between 1988 and 2014 (Tables 2 and 3). In 1988, the greatest amount of SOC storage occurred in the pasture (715 Gg) which was followed by forest (385 Gg), irrigated (364 Gg) and rain-fed (24 Gg) farmlands. Overall, because of land use change, the total amount of SOC storage was reduced by 100 Gg from 1988 to 2014 in the study area (390 km^{2}).

3.4. Potential carbon sequestration in soil

The native land use in the region was forest, and the potential carbon sequestration was calculated using Eq. (4), showing the potential carbon sequestration ranged from 7.8 to 11.3 Mg C ha^{-1}. Pastures had the highest capacity to sequester carbon (Table 4).

3.5. Quantification of the complexed organic carbon sequestration potential using the clay to carbon saturation concept

To estimate the additional amount of carbon which could be sequestered as complexed organic carbon in each land use, complexed and non-complexed carbon and clay were calculated using Eqs. (5)–(8). Then the potential additional complexed organic carbon that could be stored in the soil was conducted using Eq. (9). The average clay content at the depth of 0–30 cm ranged from 347 to 382 g kg^{-1}, and there were no significant differences between the land uses. By using n = clay/SOC concentration = 10, the average complexed clay (CC) in the pasture, forest, rain-fed and irrigated farmlands was found to be 103, 199, 92 and 101 g kg^{-1}, respectively. The relation between SOC and clay content is shown in Fig. 4 for all sampling points. The straight line was drawn according to n = clay/SOC concentration = 10, indicating the clay saturation condition with SOC (Dexter et al., 2008). Accordingly, all the soils fell under the saturation line and comprised unsaturated or non-complexed clay (NCC) showing the considerable capacity of these soils to form more complexed organic carbon and the enhancement of the SOC stocks. The higher SOC inputs in forest soils led to a greater carbon to clay ratio. Thus, these soils were closer to the saturation line.

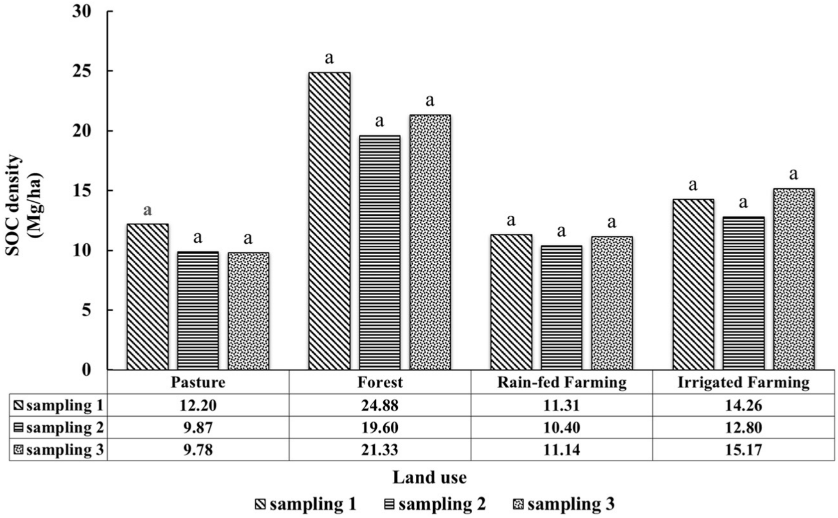

Fig. 3. Changes of soil organic carbon density (SOCD) (Mg C ha^{-1}) of the 0–30 cm soil layer in four land uses during three sampling times; in each land use, similar letters on the bars indicate non-significant difference (Duncan's multiple range, $P < 0.05$).

Table 2
Means of soil organic carbon density and storage among the land use types in 2014. (Same letters indicate no significant difference in each column of the respective depth at $P < 0.05$ with Duncan's test).

Land use	Area (ha)	SOC density (Mg ha^{-1})			Total SOC storage (Gg)			Total SOC
		0–5 cm	5–15 cm	15–30 cm	0–5 cm	5–15 cm	15–30 cm	
Pasture	18,320	6.38^{b}	10.88^{b}	15.01^{b}	116.86	199.31	275.07	591.23
Forest	2024	14.18^{a}	23.40^{a}	29.43^{a}	28.70	47.37	59.56	135.62
Rain-fed	2116	4.84^{b}	9.40^{b}	14.73^{b}	10.24	19.88	31.17	61.30
Irrigated	16,000	7.79^{b}	11.67^{b}	18.14^{b}	124.66	186.70	290.17	601.53

Since all the soils were located under the saturation line (Fig. 4), the amount of complexed clay (CC) corresponded to the complexed organic carbon (COC) (whole amount of SOC concentration) and the non-complexed organic carbon (NCOC) was equal to 0. Also, the vertical changes of CC followed the SOC changes pattern and decreased with depth in all the land uses (Table 1).

The potential additional complexed organic carbon in each land use corresponded to its non-complexed clay. Our results showed there were significant differences between land uses regarding non-complexed clay (NCC). The forest soils had the lowest NCC (183 g kg^{-1}) (Fig. 5). The other land uses had a similar condition, and > 70% of their clay content remained as NCC. Thus, there was a considerable capacity for storing more SOC in the studied soils as COC, especially in pasture and farmlands.

3.6. Correlation between SOC concentration and other variables

Correlation analysis was conducted to understand the relationship between SOC concentration and other variables in each land use (Table 5). Generally, in pasture soils, the correlation coefficients between SOC concentration and the other variables were lower than those for the other land uses. In pastures, only bulk density (in 5–15 cm depth) and sand content (in 0–5 and 5–15 cm depths) showed a negative correlation with SOC concentration. In the forest, bulk density was negatively correlated with SOC concentration in the subsoils, while, SOC concentration showed positive correlations with clay content (in 0–5 and 5–15 cm depths) and MWD (in all depths). In the rain-fed cultivation, altitude (in all depths) was correlated negatively and MWD positively correlated (in the surface soil) with SOC concentration. In irrigated farmlands, negative correlations were observed between bulk density (in 5–15 cm depth), sand content (in the subsoils), temperature (in surface soil), and altitude (in surface soil) with SOC concentration. There were also positive correlations between clay content (in subsoils) and MWD (in all depths) with SOC concentration in the irrigated farmlands. Overall, environmental variables and soil physical

Table 4
Potential soil carbon sequestrability in various land uses.

Land use	Pasture	Rain-fed farmland	Irrigated farmland
$C_{seq.}$ (Mg ha^{-1})	11.32	10.99	7.86

Table 3
Means of soil organic carbon density and storage among the land use types in 1988.

Land use	Area (ha)	SOC density (Mg ha^{-1})			Total SOC storage (Gg)			Total SOC
		0–5 cm	5–15 cm	15–30 cm	0–5 cm	5–15 cm	15–30 cm	
Pasture	22,178	6.38	10.88	15.01	141.47	241.28	332.99	715.73
Forest	5752	14.18	23.40	29.43	81.55	134.61	169.27	385.43
Rain-fed	832	4.84	9.40	14.73	4.03	7.82	12.26	24.10
Irrigated	9698	7.79	11.67	18.14	75.56	113.16	175.88	364.60

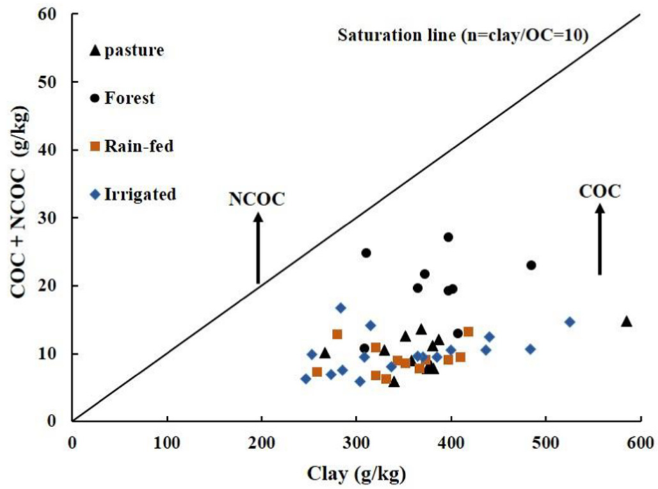

Fig. 4. Application of Dexter's clay to carbon saturation concept for 0–30 cm soil layers in different land uses. The line is the saturation line (1:10 line). Y values below the saturation line indicate the complexed organic carbon (COC).

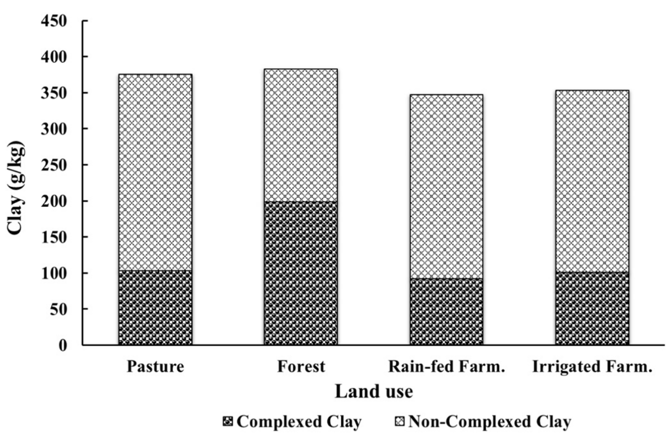

Fig. 5. Partitioning of clay content to complexed and non-complexed clays among the land uses in the region.

Table 6
Stepwise multivariate regression analyses of the soil organic carbon concentration (SOCc) in different land uses and depths.

Land use	Depth increments (cm)	Term	Unstandard coefficient	Standard coefficient	R^2 adj.	*P* value
Pasture	0–5	Constant	13.10		0.12	0.022
		Sand	−0.14	−0.38		
	5–15	Constant	22.98		0.14	0.013
		Bd	−11.75	−0.41		
Forest	0–5	Constant	0.55		0.67	0.000
		Clay	0.03	0.76		
		Silt	−0.01	−0.46		
		MWD	0.20	0.40		
	5–15	Constant	42.47		0.64	0.000
		Bd	−26.25	−0.63		
		MWD	6.38	0.34		
	15–30	Constant	78.93		0.46	0.001
		Bd	−38.28	−1.04		
		Clay	0.60	0.73		
		MWD	5.00	0.35		
Rain fed	0–5	Constant	77.27		0.56	0.000
		MWD	5.67	0.59		
		Altitude	−0.03	−0.52		
		Bd	−8.62	−0.44		
	5–15	Constant	72.86		0.37	0.000
		Altitude	−0.03	−0.55		
		Sand	−0.11	−0.43		
		MWD	3.78	0.40		
	15–30	Constant	66.02		0.46	0.000
		Altitude	−0.03	−0.57		
		Sand	−0.10	−0.47		
		MWD	3.42	0.41		
Irrigated	0–5	Constant	5.236		0.48	0.000
		MWD	0.305	0.63		
		Altitude	−0.002	−0.32		
	5–15	Constant	0.544		0.42	0.000
		MWD	0.193	0.45		
		Clay	0.007	0.42		
	15–30	Constant	0.54		0.33	0.000
		Clay	0.01	0.40		
		MWD	0.17	0.37		

Table 5
Spearman's correlation coefficients between the soil organic carbon concentration (SOCC) and environmental variables in the study area.

Land use & soil depth	Environmental variables								
	Bd	Clay	Silt	Sand	Temperature	Precipitation	Altitude	Slope	MWD
Pasture									
0–5	−0.13	0.31	0.25	−0.37*	−0.06	0.14	−0.22	−0.10	0.02
5–15	−0.39*	0.24	0.27	−0.37*	−0.04	0.08	−0.28	−0.16	−0.06
15–30	−0.002	0.08	−0.03	−0.24	−0.11	0.19	−0.26	−0.09	−0.19
Forest									
0–5	−0.28	0.44*	−0.09	−0.12	−0.07	0.44*	−0.24	0.25	0.60**
5–15	−0.62**	0.43*	−0.01	−0.11	0.03	0.24	−0.06	0.33	0.56**
15–30	−0.39*	0.13	−0.03	−0.14	−0.20	0.41*	−0.18	0.38*	0.43*
Rain-fed									
0–5	−0.14	0.29	0.02	−0.15	−0.03	0.17	−0.49**	0.13	0.29
5–15	0.18	0.26	−0.02	−0.03	−0.01	0.15	−0.49**	0.18	0.30
15–30	−0.04	0.35*	−0.11	−0.17	−0.07	0.21	−0.51**	0.08	0.32
Irrigated									
0–5	−0.01	0.39**	0.12	−0.31*	−0.32*	0.24	−0.40**	0.24	0.60**
5–15	−0.40**	0.52**	0.13	−0.43**	−0.26	0.16	−0.27	0.15	0.50**
15–30	−0.20	0.52**	0.13	−0.44**	−0.25	0.16	−0.28*	0.03	0.35*
All									
	−0.25**	0.24**	0.10*	−0.21**	−0.10*	0.15**	−0.34**	0.14**	0.56**

* and ** stand for significant relationships at 95% and 99% probability levels, respectively.

properties showed various degrees of correlation with SOC concentration in different land uses.

3.7. Linear regression models for determining the main SOC concentration controlling factors

The stepwise multiple linear regression was conducted to assess the relative contributions and the impact of independent soil (soil bulk density, clay, silt, sand, and MWD) and environmental variables (air temperature, altitude and land slope) on SOC concentration. By using this analysis, and according to different depths of each land use type, various variables were selected as the main SOC controlling factors (Table 6).

In the pasture, sand content and bulk density were the selected factors in 0–5 cm and 5–15 cm layers, which accounted for 12% and 14% of the variations of SOC concentration, respectively. The stepwise multiple linear regression was unable to determine the main controlling variables in the 15–30 cm depth for this land use. The low R^2 for pasture soils indicated that the variables used as regression inputs were not the main SOC concentration drivers in this land use (Table 6).

The highest R^2 for regression models was achieved in forest soils in all the depths. In 0–5 cm, 67% of SOC concentration variation was explained by clay, silt, and MWD. Bulk density and MWD in the 5–15 cm depth and bulk density, clay, and MWD in the 15–30 cm depth could explain 64% and 46% of the variations in SOC concentration, respectively. MWD was the most important factor in all three depths in the forest lands (Table 6).

In the rain-fed farmland, SOC concentration in the 0–5 cm depth was a function of MWD, altitude and bulk density, and these variables could justify about 56% of the SOC concentration variation. In the subsoil, altitude, sand content and MWD explained 37% and 46% of SOC concentration variation in the 5–15 cm and 15–30 cm depths, respectively (Table 6).

In the surface soils of irrigated farmlands, 48% of the SOC concentration variation was explained by MWD and altitude. The MWD and clay content were the main controlling factors in the subsoil (5–15 and 15–30 cm), explaining 42% and 33% of the SOC concentration variations, respectively (Table 6).

4. Discussion

4.1. The effect of land use on SOC concentration

Forest soils contained the greatest amount of SOC concentration in all depths. Hajabbasi et al. (1997) and Nourbakhsh (2007) have reported similar results in Lordegan as well. Different amounts of biomass input under various vegetation types (Obalum et al., 2012) and diverse land management practices could lead to different degrees of soil perturbation (Six et al., 2002a), thereby affecting the SOC concentration under different land uses. Removing or burning crop residues is a routine practice in the studied farmlands (Nourbakhsh, 2007). It seems that these operations, in addition to conventional tillage, could lead to a small amount of SOC concentration in farmlands, especially in the rain-fed area. On the contrary, deep root distribution and higher organic inputs into the forest soil surface can make them rich in SOC, in comparison to the other land uses. These results indicated that the land use change from forest to the other types implied a reduction in SOC concentration, and this reduction was considerable in the surface soil layer. Similar points have been found by other researches (Schulp et al., 2008).

The changes of SOC were monitored during one year across three sampling times. Statistically insignificant variations in the SOC density suggested that carbon sequestration studies needed a long-term period to detect significant differences in SOC density. However, we could detect small changes during the experimental period. The decreasing trend of SOC density in forest and pasture illustrated the effects of mismanagement and overgrazing on SOC density and soil quality. The forest soil had enough resilience to compensate the SOC losses to some extent during the time. But the degradation process in the pastures was more serious due to poor vegetation cover and overgrazing. Only in the irrigated farmlands, SOC accumulation had occurred at the end of study period, which could be due to the type of vegetation (dominantly alfalfa) (Fig. 3). Similar results have been reported for the bare soil and alfalfa plantation across a 7-year experimental period (Guan et al., 2016). The plant cover of the bare soil in their experiment was similar to the pasture soils in our study, and the SOC density was decreased with depth in both studies. They also reported SOC density accumulation under alfalfa plantation during the experiment, which was mainly due to the high rate of fine roots decomposition (Guan et al., 2016; Shahzad et al., 2015). Considering the 4 per mille commitment (Minasny et al., 2017), in the studied land uses including pasture, forest, rain-fed and irrigated farmlands, the SOC density would have to be increased by 0.05, 0.10, 0.05, and 0.06 Mg C ha^{-1} per year, respectively (Fig. 3). Only in the irrigated farmlands, the amount of SOC density increased even more than the expected value (6.3%) and, none of the other three land uses met the 0.4% initiative increase in their SOC density. As emphasized by Minasny et al. (2017), mostly the managed agricultural lands have the potential to increase SOC. Based on the area under different land uses in this work, approximately 60% of the soils act as carbon sources rather than sinks of carbon.

In all land uses, the SOC concentration was decreased, and SOC density (according to sampling increments) was increased with depth, that was in agreement with other studies (Dorji et al., 2014; Mulder et al., 2016). This inverse relation could occur due to the vertically increasing bulk density and wider depth increments (e.g., 5 cm in the surface, as compared to 15 cm in the subsurface). Although the surface soil contained significantly higher SOC concentration than the subsurface, the increasing bulk density, and width of increments altered the vertical SOC density distribution (Akpa et al., 2016). However, when the SOC density was calculated per centimeter of depth, the decreasing trend was obvious in all land uses except rain-fed farmlands. Generally, insignificant vertical changes of SOC concentration and SOC density in the rain-fed farmlands was probably due to the low SOC input and soil homogenization via the tillage operations. On the contrary, alfalfa was the dominant crop in the irrigated farmlands tilled every seven years. Therefore, there may be enough time for organic matter to cumulate on the surface soil of the irrigated farmlands.

4.2. Carbon sequestration potential

The maximum SOC density was observed in forestlands in all depths, which was significantly greater than other land uses and followed by irrigated farmland, rain-fed farmland and pasture. This sequence was in agreement with the results of Albaladejo et al. (2013). In comparison to humid areas like European agricultural soils with the SOC density of 53 Mg ha^{-1} (Smith et al., 1997), our study case, like other dry areas, contained considerably a low amount of SOC density (15 Mg ha^{-1}) in similar depths. This showed the importance of climatic variables in organic carbon density.

According to our results, there was a considerable potential for carbon sequestering in the region via converting three land uses including pasture, rain-fed and irrigated farmlands to the forest. This could enhance the average SOC density from 15.6 to 24.8 Mg C ha^{-1}. Regarding the area covered by pastures and farmlands, their conversion to forestland could considerably increase the SOC storage in the region. It means that afforestation could transmit a considerable amount of atmospheric carbon to the soil sink. As revealed by Guan et al. (2016), the relatively considerable carbon sequestration potential in the area reflects the degraded condition of the soils under pasture and farmlands.

Moreover, because of some socio-economic problems in the study area, there is a great tendency to convert the forests to farmlands.

Under the current circumstances, the accumulated carbon in the forest soil could be emitted to the atmosphere, accelerating the global warming and climate change problems in the region. Emission of 1 Mg carbon is equal to 3.66 Mg CO_2 (Albaladejo et al., 2013). Although food production is very important, it is necessary to notice the high deforestation rate and the low efficiency of rain-fed farming in the region. Unfortunately, the rain-fed farmlands are left uncultivated after a while, promoting the erosion risk, especially in the slope lands. All these issues are against the sustainable management of the area. Several studies have emphasized the key role of land use type in the SOC stock in the arid and semiarid areas (Hoffmann et al., 2012; Lo Seen et al., 2010). Reduction of inputs biomass, acceleration of soil erosion, and the increase of soil organic matter turnover rate are the main reasons for the SOC concentration reduction due to the conversion of forest to farmland (Albaladejo et al., 2013). Some studies have already demonstrated that the SOC loss through land use change to cultivated lands in the semiarid areas could be higher than that in the humid areas (Martinez-Mena et al., 2008).

Regarding the clay to carbon saturation concept (Dexter et al., 2008), about 70% of soil clay under pastures, rain-fed and irrigated farming remained as non-complexed clay, with a large capacity to complex SOC. The results showed that, even forest soils could store more SOC associated with its NCC and the empty capacity for sequestering carbon. However, there is a vacant capacity for storing carbon in these soils; it should also be noted that the other conditions such as climatic variables are important in carbon sequestration process as well (Dorji et al., 2014).

4.3. The main factors controlling SOC concentration

The high CV of SOC concentration suggested that in addition to land use type, there might be some other factors (such as microclimate condition, amount of vegetation cover, agricultural practices) that could influence the SOC concentration, which was in agreement with the findings obtained by Albaladejo et al. (2013) (Table 1).

Linear stepwise multiple regression analysis demonstrated that the relative importance of controlling variables changed among the soil layers and land uses (Table 6). This finding is in line with other investigations, indicating that the SOC concentration dynamics in the surface and subsurface soils (Salomé et al., 2010) and the different land uses (Albaladejo et al., 2013) may be affected differently by various factors.

Linear stepwise multiple regression was unable to detect a strong relationship between SOC and contributing variables in the pastures. It seems that other factors might have influenced the SOC concentration in pastures not considered in this study. On the contrary, the best relationships were established between SOC concentration and controlling factors in all depths of forestland, in fact, the greatest the SOC concentration, the better the relationship.

Our results showed that in all land uses except pasture, MWD was an important SOC concentration controlling factor in all depths. Many chemical and biological processes of carbon sequestration are regulated by soil physical properties such as soil aggregation or structure. Physical protection of organic matter against oxidation and decomposition occurs via soil aggregate formation and the encapsulation of the organic matter inside the aggregates (Garcia-Franco et al., 2015; Six et al., 2000a). The aggregation process promotes the organic matter stabilization, consequently increasing the residence time of the organic carbon in the soil (Berhe and Kleber, 2013; Chaplot and Cooper, 2015). On the other hand, in the soils with low aggregate stability, the breakdown of aggregates can lead to the release and oxidation of the protected organic matter (Schmidt et al., 2011), as well as increasing CO_2 emission (Chaplot and Cooper, 2015). There were significant correlations between SOC concentration and MWD in most cases, indicating the important role of bonding between clay particles and organic matter in the aggregates stabilization (Hati et al., 2007). Formation and breakdown of aggregates could considerably affect the long-term stabilization and short-term accumulation of the soil organic matter (Chivenge et al., 2011; Six et al., 2000b). Baranian Kabir et al. (2017) also found a strong relationship between SOC and MWD in the semiarid central Iran as well.

The other important soil physical attribute determined as SOC concentration controlling factor was the soil clay content. It was demonstrated that the chemical stabilization of SOM could occur via the soil organic components absorption to the fine soil particles with high surface activity (i.e., clay and silt-sized particles). This process promoted soil aggregation by providing the aggregate domain, finally compelling the physical protection of SOM (Chivenge et al., 2007; Six et al., 2000b).

Altitude was also an important SOC concentration controlling variable, especially in the farmlands. Our results pointed to the decrease of SOC concentration as altitude was increased. Several studies have indicated the role of altitude in the SOC stock. Some studies have also illustrated that there is an increasing relation between SOC stock and altitude (Girardin et al., 2010). However, other studies have shown a discontinuous increase (Schawe et al., 2007) and some others have come to no significant relationship between SOC stock and altitude (Zimmermann et al., 2010). It seems that altitude increase can lead to a temperature reduction, which in turn, decelerates photosynthesis rate, the organic matter input to the soil, and nutritional supply to plant due to the lowered decay rate of organic matter. Probably, in our study area, water scarcity and shallow soil in the high elevation lands can affect the growth of plants and photosynthesis rate as well. It has been explained in some other studies that SOC accumulation can occur by temperature increase when the rate of biomass input to the soil exceeds the decomposition rate (Xiong et al., 2014).

5. Conclusions

In this study, soil organic carbon concentration and stocks in different land uses were examined in a semiarid region in central Iran. Our results showed that the SOC concentration in the forest soil was significantly greater than that of other land uses. The mean SOC concentration ranged from 9.2 to 20.2 $g\,kg^{-1}$ in the 0–30 cm soil layer. Although the SOC concentration was low in pastures and farmlands, > 85% (1192 Gg C) of the SOC stocks were in these two land uses, because they were the dominant land uses in the area.

Because of the land use changes in the region (390 km^2) (especially deforestation), from 1988 to 2014, soil carbon stock was decreased by 100 Gg C during 26 years. Regarding the clay to carbon saturation concept, pasture and farm lands soils could physically stabilize a considerable amount of carbon by forming clay-carbon complexes. It means that if the management practices are changed toward satisfying carbon sequestration goals, the soils will have the sequestering potential to duplicate the SOC stock in the region.

The stepwise multiple regression results also suggested that SOC concentration controlling factors could vary in different land uses and soil layers. Thus, the suitable management practices should be defined to enhance carbon sequestration according to main controlling variables. Overall, the R^2 of regression models in the surface soil was higher than that in the subsoils. In cases with high SOC concentration, like forest soil layers, the relative importance of soil physical properties was great; while both the soil attributes and the climatic variables were important in the soils with low SOC. This finding suggests that SOC stock enhancement via the application of soil physical conservation methods is achievable. Long-term studies are, however, needed to monitor the impacts of applying appropriate management practices and detect the pattern of SOC stock changes in various land uses in this region.

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References

Akpa, S.I.C.C., Odeh, I.O.A.A., Bishop, T.F.A.A., Hartemink, A.E., Amapu, I.Y., 2016. Total soil organic carbon and carbon sequestration potential in Nigeria. Geoderma 271, 202–215. https://doi.org/10.1016/j.geoderma.2016.02.021.

Albaladejo, J., Ortiz, R., Garcia-Franco, N., Navarro, A.R., Almagro, M., Pintado, J.G., Martínez-Mena, M., 2013. Land use and climate change impacts on soil organic carbon stocks in semi-arid Spain. J. Soils Sediments 13, 265–277. https://doi.org/10.1007/s11368-012-0617-7.

Arshad, M.A., Lowery, B., Grossman, B., 1996. Physical tests for monitoring soil quality. In: Methods for Assessing Soil Quality. Soil Science Society of America, pp. 123–141.

Baranian Kabir, E., Bashari, H., Mosaddeghi, M.R., Bassiri, M., 2017. Soil aggregate stability and organic matter as affected by land use change in Central Iran. Arch. Agron. Soil Sci. 63, 1823–1837. https://doi.org/10.1080/03650340.2017.1308492.

Berhe, A.A., Kleber, M., 2013. Erosion, deposition, and the persistence of soil organic matter: mechanistic considerations and problems with terminology. Earth Surf. Process. Landf. 38, 908–912. https://doi.org/10.1002/esp.3408.

Cambardella, C.A., Elliott, E.T., 1993. Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. Soil Sci. Soc. Am. J. 57, 1071–1076. https://doi.org/10.2136/sssaj1993.03615995005700040032x.

Carter, M.R., Angers, D.A., Gregorich, E.G., Bolinder, M.A., 2003. Characterizing organic matter retention for surface soils in eastern Canada using density and particle size fractions. Can. J. Soil Sci. 83, 11–24. https://doi.org/10.4141/S01-087.

Chaplot, V., Cooper, M., 2015. Soil aggregate stability to predict organic carbon outputs from soils. Geoderma 243, 205–213. https://doi.org/10.1016/j.geoderma.2014.12.013.

Chivenge, P.P., Murwira, H.K., Giller, K.E., Mapfumo, P., Six, J., 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: implications for conservation agriculture on contrasting soils. Soil Tillage Res. 94, 328–337. https://doi.org/10.1016/j.still.2006.08.006.

Chivenge, P., Vanlauwe, B., Gentile, R., Six, J., 2011. Organic resource quality influences short-term aggregate dynamics and soil organic carbon and nitrogen accumulation. Soil Biol. Biochem. 43, 657–666. https://doi.org/10.1016/j.soilbio.2010.12.002.

Dexter, A.R., Richard, G., Arrouays, D., Czyż, E.A., Jolivet, C., Duval, O., 2008. Complexed organic matter controls soil physical properties. Geoderma 144, 620–627. https://doi.org/10.1016/j.geoderma.2008.01.022.

Dorji, T., Odeh, I.O.A., Field, D.J., Baillie, I.C., 2014. Digital soil mapping of soil organic carbon stocks under different land use and land cover types in montane ecosystems, eastern Himalayas. For. Ecol. Manag. 318, 91–102. https://doi.org/10.1016/j.foreco.2014.01.003.

Faggian, V., Bini, C., Zilioli, D.M., 2012. Carbon stock evaluation from topsoil of forest stands in NE Italy. Int. J. Phytorem. 14, 415–428. https://doi.org/10.1080/15226514.2011.620656.

Fang, X., Xue, Z., Li, B., An, S., 2012. Soil organic carbon distribution in relation to land use and its storage in a small watershed of the Loess Plateau, China. Catena 88, 6–13. https://doi.org/10.1016/j.catena.2011.07.012.

Garcia-Franco, N., Martínez-Mena, M., Goberna, M., Albaladejo, J., 2015. Changes in soil aggregation and microbial community structure control carbon sequestration after afforestation of semiarid shrublands. Soil Biol. Biochem. 87, 110–121. https://doi.org/10.1016/j.soilbio.2015.04.012.

Gee, G.W., Bauder, J.W., 1986. Particle-size analysis. In: Klute, A. (Ed.), Methods of Soil Analysis: Part 1. Agronomy Handbook, No 9 American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 383–411.

Girardin, C.A.J., Malhi, Y., Aragao, L., Mamani, M., Huaraca Huasco, W., Durand, L., Feeley, K.J., Rapp, J., Silva-Espejo, J.E., Silman, M., 2010. Net primary productivity allocation and cycling of carbon along a tropical forest elevational transect in the Peruvian Andes. Glob. Chang. Biol. 16, 3176–3192. https://doi.org/10.1111/j.1365-2486.2010.02235.x.

Gregorich, E.G., Rochette, P., Vandenbygaart, A.J., Angers, D.A., 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada. Soil Tillage Res. 83, 53–72. https://doi.org/10.1016/j.still.2005.02.009.

Guan, X.-K.K., Turner, N.C., Song, L., Gu, Y.-J.J., Wang, T.-C.C., Li, F.-M.M., 2016. Soil carbon sequestration by three perennial legume pastures is greater in deeper soil layers than in the surface soil. Biogeosciences 13, 527–534. https://doi.org/10.5194/bg-13-527-2016.

Guo, L.B., Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta-analysis. Glob. Chang. Biol. 8, 345–360. https://doi.org/10.1046/j.1354-1013.2002.00486.x.

Hajabbasi, M.A., Jalalian, A., Karimzadeh, H.R., 1997. Deforestation effects on soil physical and chemical properties, Lordegan, Iran. Plant Soil 190, 301–308. https://doi.org/10.1023/A:1004243702208.

Hassink, J., 1997. The capacity of soils to preserve organic C and N by their association with clay and silt particles. Plant Soil 191, 77–87. https://doi.org/10.1023/A:1004213929699.

Hati, K.M., Swarup, A., Dwivedi, A.K., Misra, A.K., Bandyopadhyay, K.K., 2007. Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. Agric. Ecosyst. Environ. 119, 127–134. https://doi.org/10.1016/j.agee.2006.06.017.

Hiederer, R., Köchy, M., 2011. Global soil organic carbon estimates and the harmonized world soil database. In: EUR 25225 EN. Publication Office of the European Union. https://doi.org/10.2788/13267.

Hoffmann, U., Yair, A., Hikel, H., Kuhn, N.J., 2012. Soil organic carbon in the rocky desert of northern Negev (Israel). J. Soils Sediments 12, 811–825. https://doi.org/10.1007/s11368-012-0499-8.

IPCC Climate Change, 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, USA.

Ko, C.H., Chaiprapat, S., Kim, L.H., Hadi, P., Hsu, S.C., Leu, S.Y., 2017. Carbon sequestration potential via energy harvesting from agricultural biomass residues in Mekong River basin, Southeast Asia. Renew. Sust. Energ. Rev. 68, 1051–1062. https://doi.org/10.1016/j.rser.2016.03.040.

Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304, 1623–1627. https://doi.org/10.1126/science.1097396.

Lal, R., 2005. Forest soils and carbon sequestration. For. Ecol. Manag. 220, 242–258. https://doi.org/10.1016/j.foreco.2005.08.015.

Lal, R., 2009. Challenges and opportunities in soil organic matter research. Eur. J. Soil Sci. 60, 158–169. https://doi.org/10.1111/j.1365-2389.2008.01114.x.

Leifeld, J., Bassin, S., Fuhrer, J., 2005. Carbon stocks in Swiss agricultural soils predicted by land-use, soil characteristics, and altitude. Agric. Ecosyst. Environ. 105, 255–266. https://doi.org/10.1016/j.agee.2004.03.006.

Lo Seen, D., Ramesh, B.R., Nair, K.M., Martin, M., Arrouays, D., Bourgeon, G., 2010. Soil carbon stocks, deforestation and land-cover changes in the western Ghats biodiversity hotspot (India). Glob. Chang. Biol. 16, 1777–1792. https://doi.org/10.1111/j.1365-2486.2009.02127.x.

Martinez-Mena, M., Lopez, J., Almagro, M., Boix-Fayos, C., Albaladejo, J., 2008. Effect of water erosion and cultivation on the soil carbon stock in a semiarid area of South-East Spain. Soil Tillage Res. 99, 119–129. https://doi.org/10.1016/j.still.2008.01.009.

Minasny, B., Malone, B.P., McBratney, A.B., Angers, D.A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z.-S., Cheng, K., Das, B.S., Field, D.J., Gimona, A., Hedley, C.B., Hong, S.Y., Mandal, B., Marchant, B.P., Martin, M., McConkey, B.G., Mulder, V.L., O'Rourke, S., Richer-de-Forges, A.C., Odeh, I., Padarian, J., Paustian, K., Pan, G., Poggio, L., Savin, I., Stolbovoy, V., Stockmann, U., Sulaeman, Y., Tsui, C.-C., Vågen, T.-G., van Wesemael, B., Winowiecki, L., 2017. Soil carbon 4 per mille. Geoderma 292, 59–86. https://doi.org/10.1016/j.geoderma.2017.01.002.

Mojiri, A., Aziz, H.A., Ramaji, A., 2012. Potential decline in soil quality attributes as a result of land use change in a hillslope in Lordegan, western Iran. Afr. J. Agric. Res. 7, 577–582. https://doi.org/10.5897/AJAR11.1505.

Mulder, V.L., Lacoste, M., Richer-de-Forges, A.C., Martin, M.P., Arrouays, D., 2016. National versus global modelling the 3D distribution of soil organic carbon in mainland France. Geoderma 263, 16–34. https://doi.org/10.1016/j.geoderma.2015.08.035.

Nelson, D.W., Sommers, L., 1982. Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Soil Science Society of America, pp. 539–579.

Nourbakhsh, F., 2007. Decoupling of soil biological properties by deforestation. Agric. Ecosyst. Environ. 121, 435–438. https://doi.org/10.1016/j.agee.2006.11.010.

Obalum, S.E., Watanabe, Y., Igwe, C.A., Obi, M.E., Wakatsuki, T., 2012. Carbon stock in the solum of some coarse-textured soils under secondary forest, grassland fallow, and bare footpath in the derived savanna of south-eastern Nigeria. Soil Res. 50, 157–166.

Poeplau, C., Don, A., 2013. Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. Geoderma 192, 189–201. https://doi.org/10.1016/j.geoderma.2012.08.003.

Poeplau, C., Vos, C., Don, A., 2017. Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content. Soil 61–66. https://doi.org/10.5194/soil-3-61-2017.

Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use change: processes and potential. Glob. Chang. Biol. 6, 317–327. https://doi.org/10.1046/j.1365-2486.2000.00308.x.

Salomé, C., Nunan, N., Pouteau, V., Lerch, T.Z., Chenu, C., 2010. Carbon dynamics in topsoil and in subsoil may be controlled by different regulatory mechanisms. Glob. Chang. Biol. 16, 416–426. https://doi.org/10.1111/j.1365-2486.2009.01884.x.

Schawe, M., Glatzel, S., Gerold, G., 2007. Soil development along an altitudinal transect in a Bolivian tropical montane rainforest: podzolization vs. hydromorphy. Catena 69, 83–90. https://doi.org/10.1016/j.catena.2006.04.023.

Schmidt, M.W.I., Torn, M.S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I.A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D.A.C., 2011. Persistence of soil organic matter as an ecosystem property. Nature 478, 49–56. https://doi.org/10.1038/nature10386.

Schulp, C.J.E., Nabuurs, G.J., Verburg, P.H., 2008. Future carbon sequestration in Europe-effects of land use change. Agric. Ecosyst. Environ. 127, 251–264. https://doi.org/10.1016/j.agee.2008.04.010.

Shahzad, T., Chenu, C., Genet, P., Barot, S., Perveen, N., Mougin, C., Fontaine, S., 2015. Contribution of exudates, arbuscular mycorrhizal fungi and litter depositions to the rhizosphere priming effect induced by grassland species. Soil Biol. Biochem. 80, 146–155. https://doi.org/10.1016/j.soilbio.2014.09.023.

Shen, P., Lukes, J.R., 2015. Impact of global warming on performance of ground source heat pumps in US climate zones. Energy Convers. Manag. 101, 632–643. https://doi.org/10.1016/j.enconman.2015.06.027.

Six, J., Elliott, E.T., Paustian, K., 2000a. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol. Biochem. 32, 2099–2103. https://doi.org/10.1016/S0038-0717(00)00179-6.

Six, J., Paustian, K., Elliott, E.T., Combrink, C., 2000b. Soil structure and organic matter I. Distribution of aggregate-size classes and aggregate-associated carbon. Soil Sci. Soc. Am. J. 64, 681–689. https://doi.org/10.2136/sssaj2000.642681x.

Six, J., Callewaert, P., Lenders, S., De Gryze, S., Morris, S.J., Gregorich, E.G., Paul, E.A., Paustian, K., 2002a. Measuring and understanding carbon storage in afforested soils by physical fractionation. Soil Sci. Soc. Am. J. 66, 1981–1987. https://doi.org/10.2136/sssaj2002.1981.

Six, J., Conant, R.T., Paul, E.A., Paustian, K., 2002b. Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant Soil 241, 155–176. https://doi.org/10.1023/A:1016125726789.

Smith, P., Powlson, D., Glendining, M., Smith, J.O., 1997. Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. Glob. Chang. Biol. 3, 67–79. https://doi.org/10.1046/j.1365-2486.1997.00055.x.

SPSS, I.B.M, 2011. IBM SPSS Statistics for Windows, Version 20.0. IBM Corp., New York.

Wilson, B.R., Growns, I., Lemon, J., 2008. Land-use effects on soil properties on the north-western slopes of New South Wales: implications for soil condition assessment. Soil Res. 46, 359–367. https://doi.org/10.1071/SR07231.

Winchell, M., Srinivasan, R., Di Luzio, M., Arnold, J., 2013. ArcSWAT Interface for SWAT2012: User's Guide. Blackland Research and Extension Center, Texas Agrilife Research. Grassland. Soil Water Res. Lab. USDA Agric. Res. Serv. Texas 3.

Wu, H., Guo, Z., Peng, C., 2003. Distribution and Storage of Soil Organic Carbon in China. 17https://doi.org/10.1029/2001GB001844.

Xiong, X., Grunwald, S., Myers, D.B., Ross, C.W., Harris, W.G., Comerford, N.B., 2014. Interaction effects of climate and land use/land cover change on soil organic carbon sequestration. Sci. Total Environ. 493. https://doi.org/10.1016/j.scitotenv.2014.06.088.

Yekom Consulting Engineering Co, 1988. Comprehensive Plan of Agriculture and Natural Resources Development in the Northern Watershed of the Karun River. Iran Ministry of Agriculture (in Persian).

Zdruli, P., Lal, R., Cherlet, M., Kapur, S., 2017. New world atlas of desertification and issues of carbon sequestration, organic carbon stocks, nutrient depletion and implications for food security. In: Carbon Management, Technologies, and Trends in Mediterranean Ecosystems. Springer, pp. 13–25. https://doi.org/10.1007/978-3-319-45035-3_2.

Zimmermann, M., Leifeld, J., Schmidt, M.W.I., Smith, P., Fuhrer, J., 2007. Measured soil organic matter fractions can be related to pools in the RothC model. Eur. J. Soil Sci. 58, 658–667. https://doi.org/10.1111/j.1365-2389.2006.00855.x.

Zimmermann, M., Meir, P., Silman, M.R., Fedders, A., Gibbon, A., Malhi, Y., Urrego, D.H., Bush, M.B., Feeley, K.J., Garcia, K.C., 2010. No differences in soil carbon stocks across the tree line in the Peruvian Andes. Ecosystems 13, 62–74. https://doi.org/10.1007/s10021-009-9300-2.